UK Health Security Agency

Occupational radiation exposure to UK Orthopaedic Surgeons

A dose monitoring exercise

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Contents

1: Introduction

This report summarises a recent radiation dose monitoring exercise undertaken during 2024 by the UK Health Security Agency's (UKHSA) Radiation Effects Department, within the Radiation, Chemical, Climate and Environmental Hazards Directorate (RCCE). As part of the exercise, UKHSA undertook physical monitoring by means of thermoluminescence dosimeters of radiation doses received by orthopaedic surgeons working in participating trauma units and at various NHS Trusts across the UK. Participating surgeons were issued with thermoluminescent dosemeters (TLDs) to be worn during a defined period and returned to UKHSA for dose reading. Alongside physical dose monitoring, associated information relating to biological sex, participant's career stage, recent radiation safety training and the availability, use and appropriateness of personal protective equipment (PPE) within their unit, was collected through use of a self-reporting electronic survey. The combination of data collected allowed insights into the radiation doses received by orthopaedic surgeons during routine activities, and the identification of any significant correlations with the demographic factors included in the survey. The aim of this exercise was to assess the occupational radiation doses routinely received by orthopaedic surgeons and any potentially influential demographic factors to support radiation protection efforts across the workforce.

Background

Breast cancer is the most common female cancer in the UK, accounting for 11,500 deaths per year [1, 2]. Around 1% of UK breast cancer incidences are attributed to ionising radiation exposure, a recognised breast carcinogen [3]. It is challenging to study the radiation exposure-breast cancer relationship within occupational cohorts due to underlying genetic and epigenetic predispositions [3]. It is generally accepted that the relationship between radiation exposure and cancer risk can be modelled for radiation protection purposes using a linear non-threshold model, under which any exposure could increase the risk of breast cancer, particularly in women [4, 5]. Much of our knowledge on radiation-related risk of breast cancer stems from the Japanese atomic bomb survivors epidemiological studies and studies of patients exposed to diagnostic or therapeutic medical radiation. Exposure at younger age is associated with increased risk of breast cancer [4]. Familial history of breast cancer has also been reported to increase a person's susceptibility to developing breast cancer [3, 6].

The majority of orthopaedic surgeons receive an annual radiation dose of less than 2 mSv/year [7], which is below the 20 mSv/year occupational dose limit set for radiation workers in the UK and implemented with support of the Health and Safety Executive (HSE) in the UK. These dose limits are based on recommendations from the International Commission on Radiological Protection (ICRP) based on the state of the art in scientific understanding of the impacts of radiation on health [8]. This exposure to ionising radiation occurs predominately during image guided procedures performed by the orthopaedic surgeons specifically. The need for image guided procedures is higher within certain sub-specialities of orthopaedics, and is particularly prevalent in the treatment of trauma, where it is used for the majority of procedures.

Breast cancer risk in orthopaedic surgeons

A study conducted on 40 members of a US workforce reported that orthopaedic surgeons typically receive mean radiation doses of around 0.02 – 0.79 mSv per month [9]. Similarly, a study of 642 orthopaedic surgeon hand doses was reported as being between 2.87 and 6.74 mGy over a 14-month period, which is around $1/100^{th}$ of the annual dose limit [10]. A 2016 study of female orthopaedic surgeons using an anthropomorphic torso phantom suggested that the most common breast cancer site, the upper outer quadrant of the body, was not sufficiently shielded during intraoperative radiation exposures. This was considered to be due to inappropriate cover caused by standard PPE aprons due to both their size and design, as well as being related to the positioning of both the surgeon and the C-arm of the radiographic imaging device [11].

A recently published epidemiological study reported an increased prevalence of both breast and all-cause cancer (invasive internal cancers and melanomas) among female orthopaedic surgeons [12]. The study was conducted using self-reported survey data from 672 orthopaedic surgeons across the United States. The primary evidence to support the claim of increased breast cancer prevalence is based on a 2.9 – 3.9 fold excess risk within female orthopaedic surgeons who are occupationally exposed to ionising radiation compared to an age matched female cohort of the general population. The validity and usefulness of this study is under some debate, with several letters to the publishing journal's editor and study author responses since publication [13, 14], summarised below. As a result of these concerns, the British Orthopaedic Association (BOA) approached UKHSA seeking assistance to perform a monitoring exercise on the UK orthopaedic surgeons.

In a rapid response letter to the editor relating to the study, Haylock [14] raised challenges suggesting that the study does not provide strong evidence that female medical workers are at increased risk of developing breast cancer due to occupational radiation exposure. There were also concerns regarding whether the comparison of self-reported data from a restricted and self-selected population is fair and appropriate. Haylock also emphasised that no attempt appears to have been made to check self-reported incidence of cancer against medical records. This would allow unambiguous identification of independent primary tumours. There is no support in the data presented by Chou et al. (2022) that ionising radiation exposure is a contributing factor in breast cancer prevalence in female orthopaedic surgeons. A similar view is shared by Farkouh et al (2023), who did not consider that the reported higher prevalence of breast cancer the US orthopaedic surgeon study cohort could be supported by the data and results presented [15]. They also highlight the possible cause for the reported increased cancer prevalence in orthopaedic surgeons could be related to the increased alcohol consumption measured within the cohort compared to the general population, a known contributing factor to breast cancer, rather than due to radiation exposure [15].

Socioeconomic status is a known risk factor for breast cancer amongst other diseases and so this should be considered in addition to age when conducting population matching; US orthopaedic surgeons are amongst the top 1% of earners in the country. Increased socioeconomic status has also been correlated to increased breast cancer survival (11, 12). Similarly, analysis of the WHO's Study on Global Ageing and Adult Health found an increased individual socioeconomic status was positively associated with breast cancer screening (13). Orthopaedic surgeons as a group are also characterised by other factors related to increased breast cancer risk, including night working and increased age at first childbirth in females [12].

However, there is currently not sufficient weight of evidence to tailor radiation protection approaches according to individual characteristics.

Considerations for reducing radiation exposure and risk

These published studies and response letters relating to suggestions of increased breast cancer risk in female orthopaedic surgeons have provoked considerable anxiety and discussion in the workforce. This is a particular concern to the profession due to the limited number of females currently in (and joining in the future) the workforce. Greater clarification on the exposures and associated risks, along with guidance for improving practice where required, is needed to ensure radiation exposure to the UK orthopaedic workforce follows the 'as low as reasonably possible (ALARP)' principles, as outlined in the UK Ionising Radiation Regulations 2017.

Whilst some key limitations of the aforementioned published studies have been discussed, questioning the validity and appropriateness of study techniques and design towards meaningful conclusions, there remains a genuine concern that an increased breast cancer risk amongst female orthopaedic surgeons could dissuade females from joining the profession. As of September 2023, there are 7,243 orthopaedic surgeons in the UK. Of these, 18% are female. Especially notable is that only approximately 8% of UK orthopaedic consultants are female, which is the lowest female representation in any speciality in the UK. However, around 30% of trainees are female, which suggests progression towards greater equality in male to female ratios, and this is a trend that should not be discouraged. The current exercise aims to clarify whether any disputed increased risk of breast cancer in female orthopaedic surgeons could be related to occupational exposure to ionising radiation.

Specific radiological protection measures have been recommended by the British Orthopaedic Association to ensure orthopaedic radiation dose to the axilla and chest area is kept as low as reasonably practicable. These include recommendations for the operator standing perpendicular to the radiation beam, ensuring protective screens are placed appropriately, the operator positioning their body to ensure axilla and chest are as far as possible from the beam, keeping arms down when screening and avoiding the 90-degree lateral view when possible. Current recommendations and availability of effective and appropriate personal protective equipment (PPE) may be inconsistent across the various units and centres that orthopaedic surgeons operate. Specific PPE designed to reduce radiation exposure to the breast and axilla region of the female torso have been identified [16], and further investment is needed to encourage and wearing and availability of these. The BOA recommend a minimum lead thickness of protective gowns and aprons to be 0.35 mm for all orthopaedic surgeons during operations involving radiation procedures. However, studies have reported that the gowns currently in use may not offer the adequate protection needed to shield the breast tissue [11, 15, 16].

It should be noted that occupational radiation doses received by orthopaedic surgeons are by no means the highest amongst medical specialities, although they have been reported to have an increased risk of breast and all cancer that was not observable in urologists or plastic surgeons [17]. Interventional cardiologists are generally thought to receive the highest medical occupational doses, around 8 mSv/year [18], and with no indication of significantly increased breast cancer in female workers [19, 20]. However, radiation protection practices in interventional cardiologists are generally improving due to an enhanced focus on this occupational group [21, 22] and now many of these workers are classified as radiation workers. Orthopaedic surgeons are, to date, not considered to be classified radiation workers in most UK hospitals; they are not part of the National Registry for Radiation Workers, and therefore are not routinely monitored for radiation exposure. Furthermore, formal instruction in radiation safety is not currently a mandatory part of orthopaedic surgeon training (British Orthopaedic Association standards and guidance).

A previous study of British orthopaedic surgeons has indicated a lack of training in radiation protection (38% of surgeons received no formal training) and lack of basic knowledge, legislation, and practicalities of the use of ionising radiation (406 surveyed surgeons) [7]. A recent review of surveys covering 2,209 orthopaedic surgeon responses identified a low knowledge of the ALARP principle and general radiation protection practices [23]. In addition, only 20% of respondents across the surveys collated answered that they had received any radiation protection training when asked. Additionally, previous studies of various medical profession specialisms indicated varying uptake of PPE across different hospitals and centres [24, 25] . The Ionising Radiations Regulations 2017, section 15, states that all employers must provide appropriate training on the use of ionising radiation and protection including risks and precautions. This training should be repeated at appropriate intervals, although specific timings are not given.

A comprehensive 2024 systematic literature review of ocular safety in orthopaedic surgeons found that surgeons who perform high-volume fluoroscopy-intensive procedures may be at risk of exceeding annual dose limits for eye lens radiation exposure [26]. Whilst focused on eye lens dose, the study identifies the use of appropriate lead glasses, standard vertical configuration of the C-arm, and standing perpendicular to the fluoroscope act as effective protective measures to reduce radiation exposure.

A 2018 review of radiation exposure and possible health effects in orthopaedic surgeons highlighted the limited understanding of occupational safety in these workers, as supported by the studies mentioned above, with a need for standardised education to ensure radiation exposures remain ALARP [27]. A basic understanding on the principles of radiation exposure limits, ALARP, and familiarisation with current knowledge of health effects is needed in orthopaedic surgeons, with further efforts needed to explore how best to deliver this to relevant workers [27].

All employers of radiation workers are required to provide radiation protection training, typically delivered through radiation protection advisors, as necessary and at suitable intervals, although the Ionising Radiation Regulations 17 do not specify how frequent these should be. Workload pressures, and a perception of low priority in some professions, may need addressing. Some professions have taken it upon themselves to provide recommendations for radiation safety training to ensure their workers are better informed and protected and link this to professional registration requirements; within dentistry radiation workers, there is a requirement to complete 5 hours of radiology and radiation protection training within each 5-year CPD period. There is a general expectation to deliver radiation protection training to workers every 3 – 5 years, however there is no legal obligation within IRR17. Within the UK and across the NHS, radiation protection policy is decided at Trust level, rather than nationally across the NHS, and so there are discrepancies in radiation protection training across orthopaedic surgery and other medical specialties.

2: Methods

The monitoring exercise proposal was submitted to the Research Support and Governance Office (RSGO) for review by the UKHSA Research Ethics and Governance Group (REGG) and approval was granted in December 2023 (Ref 562). The exercise aimed to recruit up to 100 participants for both external radiation dose monitoring and survey completion. Following guidance from BOA, major trauma centres and trauma units across the UK were contacted to request participation and provided with an information sheet outlining the expectations of the exercise to be sent to eligible participants. Each participating site was asked to recruit trauma orthopaedic surgeons at differing career stages (from registrar and above, where regular radiation exposure in operating theatre is expected), to complete physical radiation dose monitoring using thermoluminescent dosemeters (TLDs) issued by UKHSA Personal Dosimetry Services and complete a short anonymous survey, with consent being taken for each participant as part of the initial online electronic survey provided within the information sheet. Participants were requested to be currently working (as a trainee or experienced surgeon) with some exposure to radiation, performing at least 1 operating session (equivalent to half a day) per week. The exclusion criteria, other than being a non-orthopaedic surgeon, was for surgeons who do not perform trauma procedures as part of their routine practice. The exercise did not recruit participants from other working groups who are occupationally exposed to radiation. Participants could withdraw from the exercise at any time by contacting a member of the UKHSA team with no need to state a reason.

The radiation dose monitoring exercise comprised of two measurements. Firstly, the total radiation dose received by orthopaedic surgeons over a three-month period was monitored using thermoluminescent dosemeters (TLDs). The dosemeter is worn as a badge containing an insert which contains a wrapped aluminium card containing two pellets of specially doped lithium fluoride which are sensitive to radiation. One pellet is covered by a thick filter of PTFE and polypropylene, allowing the assessment of the equivalent dose to the body. The other pellet is positioned behind a circular open window and is therefore only covered by the thin wrapper, allowing the assessment of the equivalent dose to the skin. When the dosemeters are returned to UKHSA, automatic laboratory processors heat them to approximately 250°C. The dosemeters then emit light in an amount proportional to the total radiation dose received since the dosemeter was issued. The minimum reported dose is 0.05 mSv; doses from naturally occurring, background radiation are taken into consideration. An automatic subtraction of 2.47 uSv is made for every day that the dosemeter is issued for; the national UK average for daily background radiation.

Figure 1 | Image sent to participants for guidance on TLD positioning.

Prior to the start of the observation period for each participating unit/department, TLDs were sent to each of 32 participating NHS trusts and issued to 268 surgeons who were asked to wear two badges each whilst performing radiation-related orthopaedic procedures. Participants were advised to wear the TLDs on the outside of their clothing, pinning/clipping one badge on the torso (chest area) under the protective gown and the other under the arm on the seam of the scrubs, as per figure 1, in the participant guide. Positioning in this way allowed for capture of radiation doses received to the axillary breast tissue area, which may or may not be effectively shielded by PPE worn depending on normal working habits of the individual. Participants were instructed to wear their TLDs for three months continuously while operating, before returning the TLDs to UKHSA for dose reading. A total of 295 TLDs from 154 surgeons at 22 trusts were returned at the end of the 3-month wear period.

Secondly, participating orthopaedic surgeons were sent an electronic questionnaire to capture self-reported information on the use and availability of PPE (including lead thickness, styles and sizes), biological sex, career stage and the approximate number and type of radiation-related procedures they perform. The survey also requested information regarding what recent radiation safety or protection training they had received (within in the past three years). Table 1 summarises the information captured in the electronic survey. Each surgeon was given a unique code which was linked to both their TLD readings and questionnaire responses, allowing these data to be linked while surgeons could remain anonymous.

Question	Answer Type
1. What is your study participant code? (for example, Orthopaedic 1, Orthopaedic 2 etc.)	Short open response
2. What is your biological sex?	Multiple choice (Male/Female/Prefer not to say)
3. At what stage in your career are you currently? (For staff grade and non-training posts, please choose the grade that you feel most closely reflects your level and experience)	Multiple choice (Core Trainee/Higher Trainee/Fellow/Consultant)
4. Do you work in a:	Multiple choice (MTC/Trauma Unit)
5. How many operating sessions involving x-rays/II do you perform in an average week? (Session = half day or equivalent) – please do not put any information that could identify yourself.	Short open response
6. Do you perform spinal or pelvic procedures in your current position	Multiple Choice (Yes/No)

7. What Personal Protective Equipment do you routinely wear for cases involving II?	Multiple Choice (Tabard, Two-piece vest and skirt/Vest with sleeves/Other – optional comment)
8. Thickness	Multiple Choice (0.25/0.35/not sure/Other – optional comment)
9. What size?	Short open response
10. Do you wear a thyroid shield?	Multiple Choice (Yes/No/Sometimes)
11. Do you have access to a range of PPE (sizes, types etc) in your current working environment?	Short open response
12. Prior to agreeing to take part in this study, were you individually monitored for radiation dose exposure within the last 12-24 months? If yes, provide details – please do not put any information that could identify yourself.	Short open response
13. What training have you received regarding working with radiation within the past 3 years? Please state 'none' if you have received no training – please do not put any information that could identify yourself.	Short open response

Table 1 | Questions on the electronic survey sent to participants and answer types.

The TLD and questionnaire data were both analysed individually and linked by surgeon code. The linked data was analysed for correlations between dose and sex, career stage, working environment, and PPE usage. Comments on PPE availability and training were analysed by manual grouping into common themes. Where surgeons had completed the survey multiple times, their most recent response was used for analysis. Results of this analysis can be found in section 3.

Collaboration with the British Orthopaedic Association

BOA had invited UKHSA to assist in undertaking a radiation dose monitoring exercise to investigate radiation exposure in orthopaedic surgeons on behalf of their members based on concerns raised by the recent publication(s) reporting increased incidence and risk of breast cancer within the workforce, as discussed earlier in this report. The primary driver of this exercise was to alleviate anxiety across the workforce, to not dissuade female workers from joining the profession, and to identify and support areas for improved radiation protection practice and dose monitoring to ensure the workforce can be appropriately protected. Input from BOA was critical in designing an exercise that collected information and data relevant to the workforce to ensure findings had the potential to identify improvements to radiation protection practise if appropriate.

BOA liaised with NHS Trusts with relevant trauma units and major trauma centres, and were able to identify local leads and radiation protection advisors as contacts to request and encourage participation and share information sheets explaining the exercise and requesting involvement. Whilst BOA were able to raise awareness of the exercise across various platforms and meetings to maximise reach to potential workforce participation, they had no knowledge as to who was recruited and participation remained fully anonymous to all study team members.

3: Results

The 189 surgeons who participated in the exercise represent only a small proportion of the total population of orthopaedic surgeons in the UK and therefore the results cannot be generalised. As of September 2023, 7,243 orthopaedic surgeons were recorded to be practising across the UK, with 18% identifying as female. In the present study, we have biological sex data for 114 of the 189 participants, of which 38% are female, significantly higher than would be representative for the workforce demographic. Similarly, 49% and 42% of the survey cohort were consultants or trainees respectively, which compares to 40% and 51% respectively of the total UK orthopaedic workforce demographic as a whole. It should be noted that the figures comparing workforce data do not consider the exclusion criteria of the monitoring exercise.

There is a lack of physical dosimetry data from orthopaedic surgeons in published literature which is a limitation for linking radiation dose to health outcomes within this workforce. This is further supported by the findings of this monitoring exercise, whereby 90% of orthopaedic surgeons who participated stated that they are not routinely monitored for personal radiation exposure. It should be noted that dose monitoring through the wearing of TLDs for the purpose of this exercise could have indirectly influenced behavioural changes towards greater awareness of radiation safety, thus modifying participant habits.

3a Survey

A total of 114 surgeons completed the electronic survey. Of these participants, 71 (62%) were male and 43 (38%) were female. The distribution of surgeons' primary place of work was relatively even, with 59 surgeons (52%) working at a trauma unit and 55 (48%) working at a major trauma centre. The average (mean +/- SD) number of procedures performed per week by surgeons within the cohort was 3.2 +/- 1.6. Figure 2 shows summary statistics of the cohort.

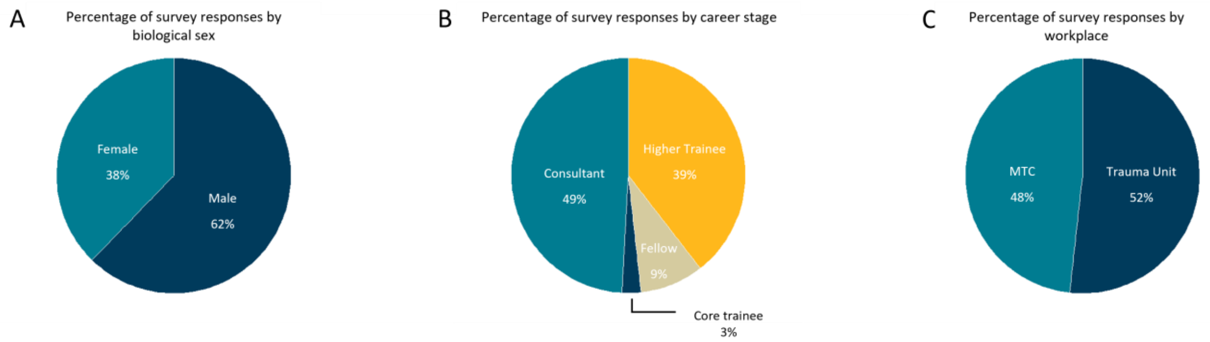

Figure 2 | Summary information about the surveyed cohort.

Radiation safety training

Low awareness and access to sufficient and appropriate radiation safety training and tools has been highlighted in previous surveys of orthopaedic surgeons within the UK. A recent nationwide survey was conducted across 406 UK orthopaedic surgeons in 2021 [7]. 92% of respondents reported using intraoperative ionising radiation at least once per week, and 38% of those surgeons reported receiving no formal training in working with radiation or radiation safety. Only 19% of respondents considered themselves to have received adequate safety training in using equipment emitting ionising radiation. Limited knowledge of basic principles of radiation protection and associated legislation was observed across participating surgeons. Similarly, our present exercise has found that 58.8% of all survey respondents had received no training to safely work with radiation in the past 3 years, considerably higher than as reported in the 2021 study indicating a possible decline in radiation safety teaching and training over recent years, albeit with different question wording which would make the two studies not entirely comparable. There is no significant association between career stage (trainee to consultant) or biological sex and radiation safety training undertaken in the past three years (chi squared test, $p > 0.47$).

Personal Protective Equipment (PPE)

The free text comments collected within the survey suggest a lack of appropriate PPE availability for orthopaedic surgeons. 58 of the 114 participants (50.1%) report they did not have access to a range of styles or sizes of PPE in their current workplace. 32 surgeons identified a lack of size and/or style availability, and 10 commented on issues with PPE access in busy periods in the operating theatres. 7 surgeons noted a lack of access to thyroid shields, and a further 5 mentioned poor coverage or axilla protection. This would suggest a lack of appropriate PPE in terms of style and size, as well as suggesting issues with availability for orthopaedic surgeons. It is worth noting 5 surgeons felt the PPE they did have access to was of poor quality and/or old. Lack of availability of protective equipment has been reported elsewhere [24], highlighting an important area of improvement for radiation protection practice.

We observe a significant difference in PPE style preference between male and female workers, with more females using two-piece PPE and more males using a tabard (chi squared test, $p=0.00166$). We also found that a significantly higher proportion of female surgeons were opting to use thyroid shields than male surgeons (chi squared test, $p=0.0354$). One third of surveyed surgeons (38 of 114) were unsure what thickness of lead lining they wear.

Lead or lead equivalent gowns are advised to be worn to reduce the radiation dose received by orthopaedic surgeons during procedures utilising radiation exposure. However, studies have reported that the gowns currently in use may not offer the adequate protection needed to shield the breast tissue [11, 15, 16]. Results from the survey performed during this monitoring exercise would suggest greater clarity is needed to educate surgeons on what PPE they should be wearing to reduce exposures, and that appropriate PPE needs to be made available in sizes and styles compatible with all workers and for all types of surgical procedures.

3b Personal dosimeters

At the end of the monitoring period, 295 TLDs were returned for reading from a total of 154 surgeons across 22 trusts. We found that 137 of these surgeons showed a dose reading of zero during the three month wear period, meaning their TLDs were not exposed to a radiation dose above their detection limit in this time. Each TLD provides a measure of the radiation dose received to the body and to the skin in mSv. Body doses are in terms of effective dose, skin doses are in terms of equivalent dose. The Ionising Radiations Regulations 2017 state that the limits on maximum dose for any employee are 20 mSv per calendar year to the body (effective dose) and 500 mSv/year to the skin (equivalent dose) as applied to the dose averaged over any area of 1 cm^2 regardless of the area exposed.

All the doses recorded in this study were well below these limits, with the maximum recorded dose in the three-month wear period being to the body on the underarm/axillary badge of 1.84 mSv.

There is also a legal requirement under the Ionising Radiations Regulations 2017 for the setting of a dose investigation level (DIL) by any employer of radiation workers. The employer is responsible for determining their own DIL, after seeking advice from their radiation protection adviser. The regulations set a maximum DIL of 15 mSv per calendar year but often it is set much lower by the employer and correlated with the expected doses for the specific work, often 1-2 mSv and rarely more than 5-6 mSv per calendar year. Where a dose investigation level has been exceeded, an investigation must be carried out to review working conditions to make sure that exposure is being restricted so far as is reasonably practicable and determine if there has been a failure of engineering, administrative or PPE controls. The duty to carry out the investigation lies with the employer of the person who has exceeded the dose investigation level. Therefore, assuming the legal DIL for the cohort of orthopaedic surgeons monitored (15 mSv per year), all surgeons monitored were well under investigation limits. However, if the person receiving the maximum dose observed in this exercise of 1.84 mSv in the three month wear period were to continue working at this level of exposure for a year, they would accrue a dose of 7.36 mSv. Under many employers this might trigger an investigation.

We found a significant difference in the mean dose to the body of the underarm/axillary area (mean +-SD = 0.0242+- 0.158 mSv) compared to the under apron/chest area (mean +-SD = 0.0149+- 0.123 mSv) (zero inflated wilcox test, p=0.0228) [28]. We found no significant difference in the mean dose to the skin of the underarm/axillary area (mean +-SD = 0.0247+- 0.145 mSv) compared to the under apron/chest area (mean +-SD = 0.0168+- 0.128 mSv) (zero inflated wilcox test, p=0.186).

The increased mean dose to the axillary tissue compared to the tissue covered by the protective apron is in line with previous findings [11] and highlights the importance of well-fitting and good quality PPE; however, the exposure is still well within the annual dose limits in the Ionising Radiations Regulations 2017. Post-hoc power calculations suggest data would need to be collected from over 4700 surgeons in order to obtain statistical significance if there is a true difference between the underarm and under apron skin doses.

3c Combined results

UKHSA received both TLD dosemeter and the associated survey data from a total of 79 surgeons. We identified no significant association between any of the factors considered in the survey (biological sex, workplace type, type/number of procedures performed, PPE availability and usage, training in the past 3 years) and the radiation exposure dose received by the surgeons (Table 2).

Factor	Test Performed	P-Value
Career Stage	Kruskal-Wallis rank sum	> 0.965
Biological Sex	Kruskal-Wallis rank sum	> 0.115
Type of Workplace	Kruskal-Wallis rank sum	> 0.331
Type of procedures performed	Kruskal-Wallis rank sum	> 0.681
PPE thickness	Kruskal-Wallis rank sum	> 0.881
Training	Kruskal-Wallis rank sum	> 0.285
Number of procedures performed	Spearman rank correlation	> 0.476

Table 2 | Statistical tests performed to look for differences in dose with the variables measured in the electronic survey. All calculations performed in R. Relevant test performed 4 times to measure association of each variable with all combinations of underarm/underapron and skin/body doses. Benjamini Hochberg multiple test correction applied. P value shown is the lowest of the 4 calculated. No significance was observed with any of the variables.

Despite identifying no significant association between biological sex and radiation dose, we observed a significantly higher underarm/axillary dose (skin dose: mean +-SD = 0.0325+-0.0719 mSv, body dose mean +-SD = 0.0243+-0.0538 mSv) compared to underapron/chest dose (skin dose: mean +-SD = 0.000+-0.000 mSv, body dose: mean +-SD = 0.000+-0.000 mSv, note that all underapron/chest dosimeters returned from female surgeons had zero readings) in female participants that was not observed in the male cohort (zero inflated wilcox test, $p \approx 0.000$) (figure 3). It should be noted that the females analysed here consist of 24 individual surgeons who returned both dose and survey (biological sex) data, therefore data from more individuals would be needed to confirm this finding. If found reproducible in larger cohorts, this could support previous studies which suggest poor fitting of PPE for female surgeons [11]. Additionally, commercially available lightweight, affordable and manoeuvrable accessories have been identified as needing consideration by employers to source and make available to surgeons to ensure adequate protection of the female torso [13].

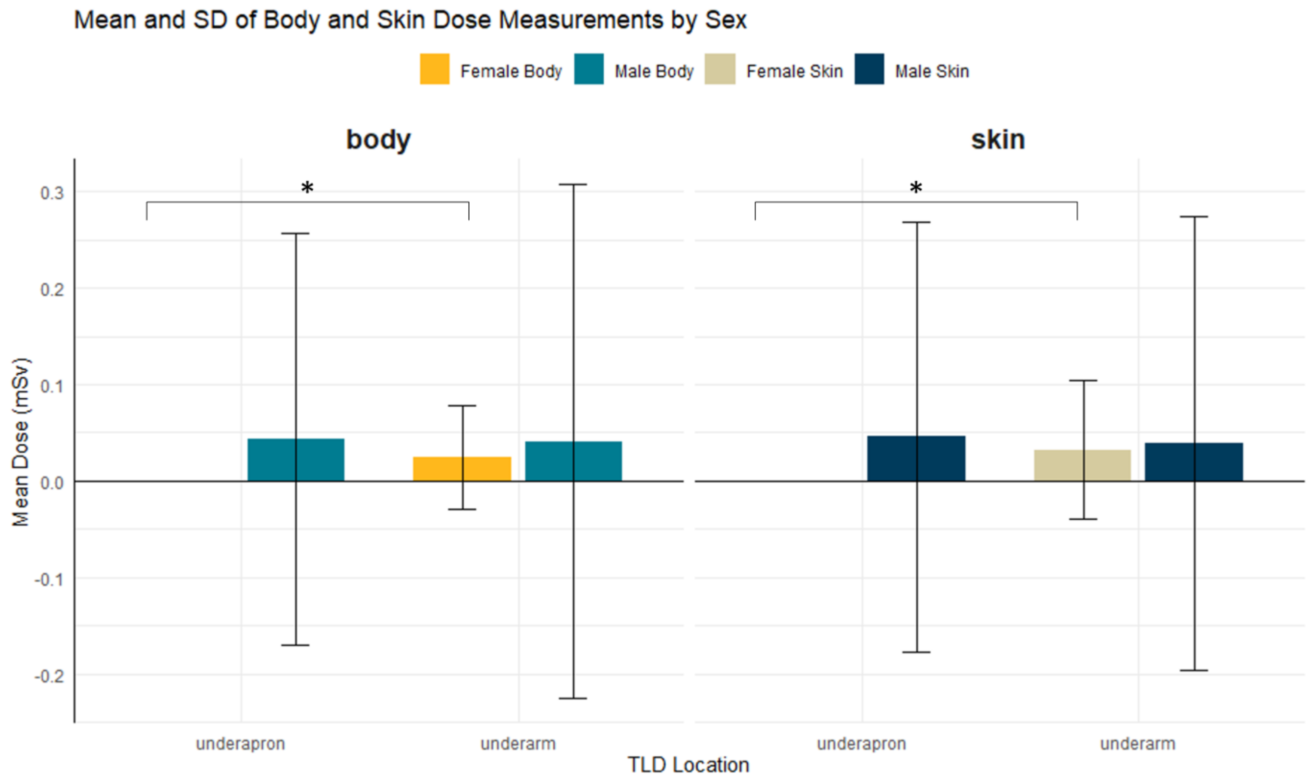

Figure 3 | Mean +/- SD of dose measurements from TLDs separated by biological sex and badge measurement type and location. * indicates statistical significance at P=0.05 according to zero inflated wilcox test.

4: Conclusions

This report summarises the radiation dose monitoring study undertaken by the UK Health Security Agency with the aim of gaining information on occupational radiation exposures in UK orthopaedic surgeons, and to identify associations between radiation dose exposure and biological sex, career stage, number of procedures performed, recent radiation safety training and the use and availability of appropriate radiation protective equipment. A total of 189 surgeons were personal dose monitored for a continuous 3-month period. Our findings suggest that whilst surgeons, as with the majority of radiation workers, likely receive a radiation exposure greater than that of the general population, no surgeons were found to have received a dose that would put them at risk of exceeding the 20 mSv yearly dose limit set by HSE's Ionising Radiations Regulations 2017.

Following personal dose monitoring and information collated from the self-reporting survey, no factor included in the survey was found to significantly influence radiation exposure dose.

We report a lack of radiation protection training in the orthopaedic workforce surveyed, with 58.8% of respondents not having had any form of radiation protection training in the past three years. This is consistent with previously published studies identifying a lack of radiation safety training and general awareness of the basic principles of radiation protection across this workforce. This suggests an area for improvement to ensure orthopaedic surgeons' knowledge around best radiation protection practice enable them to be better protected and reduce risk in the future.

This observation of a lack of radiation protection knowledge was further supported by the 33% of respondents unsure of the lead thickness they were wearing whilst operating, suggesting a possible need for standardised guidance on appropriate lead thickness requirements in gowns across all units and centres across the UK.

We report a statistically significant increase in the radiation dose received to the TLDs worn in the axillary region compared to those worn on the chest in the female participants which was not present in the male surgeons. This may indicate poorly-fitting or inappropriate PPE and availability of PPE designed to protect the breast tissue as reported elsewhere [11]. The suggested use of sleeved protective garments and/or axillary shields [16] could provide better protection of the breast tissue area in female surgeons and need further consideration for widespread use in order to fully protect the workforce.

However, due to the small sample size of the monitored population, more data is needed to assess the potential for increased dose to the axilla region of the female torso and the appropriate PPE for this population.

The BOA have created a working group aimed at identifying and understanding radiation exposure risks and improving protective measures in orthopaedic surgeons, with advice already issued to workers on the most suitable and appropriate PPE to be worn during procedures involving radiation use. Based on the results of this exercise, workers could also benefit from development of a standardised radiation protection training scheme. This finding is consistent with several recent publications and reviews reporting a general lack of radiation protection training and awareness of basic radiation protection principles among orthopaedic surgeons, suggesting an area for improvement. Further investment towards addressing the potential poor fit and effectiveness of currently available PPE for female surgeons, perhaps using a larger sample size, is indicated from these findings.

As mentioned previously, orthopaedic surgeons are not currently registered radiation workers, meaning they are not routinely monitored for radiation exposure. The National Registry for Radiation Workers (NRRW) is the long-term epidemiological study (50 years to date) of UK radiation workers who are individually monitored for radiation exposure. To date, there are around 300,000 members. When an employer of radiation workers signs up to NRRW, their current and future staff are informed of the aims of the study and asked to join. Ongoing dose data is then provided to the study and follow-up data (deaths and cancer registrations) are obtained from national sources to examine radiation risk. In this way, participation in the study would allow the long-term health of orthopaedic surgeons to be monitored and assessed. More details of the NRRW are available from UKHSA or at:
https://www.gov.uk/government/publications/radiation-workers-and-their-health-national-study

References

1. UK, C.R. *Breast cancer statistics*. [cited 2025 4th February]; Available from: https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/breast-cancer#heading-Eight.
2. UK, C.R. *Cancer incidence for common cancers*. [cited 2025 10th February]; Available from: https://www.cancerresearchuk.org/health-professional/cancer-statistics/incidence/common-cancers-compared#heading-Two.
3. Ronckers, C.M., C.A. Erdmann, and C.E. Land, *Radiation and breast cancer: a review of current evidence.* Breast Cancer Res, 2005. **7**(1): p. 21-32.
4. Helm, J.S. and R.A. Rudel, *Adverse outcome pathways for ionizing radiation and breast cancer involve direct and indirect DNA damage, oxidative stress, inflammation, genomic instability, and interaction with hormonal regulation of the breast.* Arch Toxicol, 2020. **94**(5): p. 1511-1549.
5. Measurements, N.C.o.R.P.a., *Commentary No. 27 – Implications of Recent Epidemiologic Studies for the Linear-Nonthreshold Model and Radiation Protection*. 2018.
6. Eidemüller, M., et al., *Evidence for Increased Susceptibility to Breast Cancer From Exposure to Ionizing Radiation Due to a Familial History of Breast Cancer: Results From the Swedish Hemangioma Cohort.* Am J Epidemiol, 2021. **190**(1): p. 76-84.
7. Raza, M., et al., *Radiation in orthopaedics (RIO) study: a national survey of UK orthopaedic surgeons.* Br J Radiol, 2021. **94**(1125): p. 20210736.
8. ICRP, *The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103.* 2007.
9. Gausden, E.B., et al., *Tracking Cumulative Radiation Exposure in Orthopaedic Surgeons and Residents: What Dose Are We Getting?* J Bone Joint Surg Am, 2017. **99**(15): p. 1324-1329.
10. Giordano, C., et al., *EVALUATION OF THE RADIATION DOSE TO THE HANDS OF ORTHOPAEDIC SURGEONS DURING FLUOROSCOPY USING STORED IMAGES.* Radiat Prot Dosimetry, 2020. **189**(2): p. 157-162.
11. Valone, L.C., et al., *Breast Radiation Exposure in Female Orthopaedic Surgeons.* J Bone Joint Surg Am, 2016. **98**(21): p. 1808-1813.
12. Chou, L.B., et al., *Increased Prevalence of Breast and All-cause Cancer in Female Orthopaedic Surgeons.* J Am Acad Orthop Surg Glob Res Rev, 2022. **6**(5).
13. Pilkington, I., et al., *Protecting female healthworkers from ionising radiation at work.* Bmj, 2023. **381**: p. e075406.
14. Haylock, R.G.E., *Re: Protecting female healthworkers from ionising radiation at work.* BMJ, 2023. **381**.
15. Farkouh, E.K., et al., *Reply to "Increased Prevalence of Breast and All-cause Cancer in Female Orthopedic Surgeons": Alcohol Consumption as a Possible Contributing Factor.* JAAOS Global Research & Reviews, 2023. **7**(9): p. e22.00272.
16. Van Nortwick, S.S., et al., *Methods for Reducing Intraoperative Breast Radiation Exposure of Orthopaedic Surgeons.* J Bone Joint Surg Am, 2021. **103**(17): p. 1646-1651.

17. Loretta B. Chou, L.B.L., Alex H.S. Harris, Ashley J. Brandon, Sabine Girod, Lesley M. Butler, *Cancer Prevalence among a Cross-sectional Survey of Female Orthopedic, Urology, and Plastic Surgeons in the United States.* Women's Health Issues, 2015. **25**(5): p. 476-481.
18. Kim, K.P., et al., *Occupational radiation doses to operators performing fluoroscopically-guided procedures.* Health Phys, 2012. **103**(1): p. 80-99.
19. Veillette, J.B., et al., *Occupational Risks of Radiation Exposure to Cardiologists.* Curr Cardiol Rep, 2024. **26**(6): p. 601-622.
20. Buchanan, G.L., et al., *The occupational effects of interventional cardiology: results from the WIN for Safety survey.* EuroIntervention, 2012. **8**(6): p. 658-63.
21. Ariel Durán MD, F., Sim Kui Hian MBBS, FRACP, Donald L. Miller MD, John Le Heron BSc(Hons), FACPSEM, Renato Padovani PhD, Eliseo Vano PhD, *Recommendations for occupational radiation protection in interventional cardiology.* Catheterization & cardiovascular interventions, 2013. **82**(1): p. 29-42.
22. Alejandro Gutierrez-Barrios, D.C.-P., Inmaculada Noval-Morillas, Livia Gheorghe, Ricardo Zayas-Rueda, German Calle-Perez, *Radiation protection for the interventional cardiologist: Practical approach and innovations*
23. Rowantree, S.A. and C. Currie, *Orthopaedic surgeons' knowledge and practice of radiation safety when using fluoroscopy during procedures: A narrative review.* Radiography (Lond), 2024. **30**(1): p. 274-281.
24. Barbosa AHP, M.R., Corpa AMR, Higa FS, Souza MT, Barbosa PL, Moreira AC, Quadros AS, Lemke VMG, Cantarelli MJC, *Prevalence of Lens Opacity in Interventional Cardiologists and Professional Working in the Hemodynamics in Brazil.* Arq Bras Cardiol, 2019. **112**(4): p. 392-399.
25. Mohsen Raza, R.G., James Houston, Rachel Williams, Alex Trompeter, *Radiation in orthopaedics (RIO) study: a national survey of UK orthopaedic surgeons.* British Journal of Radiology, 2021. **94**(1125).
26. Arnold, K.E., et al., *Is Ocular Safety in Orthopaedics Overlooked? A Systematic Review of Annual Ocular Radiation Exposure and Protective Measures.* Clin Orthop Relat Res, 2024. **482**(11): p. 1954-1967.
27. Hayda, R.A., et al., *Radiation Exposure and Health Risks for Orthopaedic Surgeons.* J Am Acad Orthop Surg, 2018. **26**(8): p. 268-277.
28. Wanjie Wang, E.Z.C., Hongzhe Li, *Truncated Rank-Based Tests for Two-Part Models with Excessive Zeros and Applications to Microbiome Data*. 2022.

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